Ocean and Coastal Management 151 (2018) 1–9

Contents lists available at ScienceDirect

Ocean and Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Spot, log, map: Assessing a marine virtual citizen science program against Reed's best practice for stakeholder participation in environmental management

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1. Introduction

Citizen science has seen a recent burgeoning of interest, public involvement and diversity of programs developed for participation (Thiel et al., 2014; Follett and Strezov, 2015; Silvertown, 2009). It has become progressively important, both for its ability to engage volunteers to assist in generating observations at scales or resolutions impossible to attain by individual researchers, but also in enabling a coupling between natural and human approaches. Citizen science builds the capacity for researchers to access local knowledge and implement conservation projects that might be impossible otherwise (Kobori et al., 2016).

Largely terrestrial in origin, and event/action based in nature, marine citizen science projects have started to gather momentum. Marine citizen science projects are the same as terrestrial ones in that they encourage people that may not have formal scientific training to collect, interpret and contribute to formal scientific studies, whether in collaboration with scientists or community driven (Wald et al., 2016). Unlike terrestrial research, large-scale marine citizen science projects are under-represented and underutilized for marine conservation initiatives (Roy et al., 2012; Cigliano et al., 2015). Instead, they tend to be either local in scale, or single species focused (Chin, 2014). Most are associated with the collection of scientific data to study negative impacts upon the marine environment (Thiel et al., 2014).

Marine citizen science projects have been under-represented and not well understood because factors not encountered in terrestrial contexts hamper their development. For example, access to the marine environment is difficult and it is harder to 'see' what is under water, making it more challenging to encourage people to participate (Cigliano et al., 2015). Often, specialist skills and expensive equipment are required, such as SCUBA certification, which might exclude many potential participants (Goffredo et al., 2010). Safety and public liability issues are also factors reducing the appeal of conducting marine citizen science initiatives. However, the availability of affordable electronic devices, such as high definition underwater cameras, has alleviated some data collection issues (Bear, 2016).

However, evidence shows that marine citizen science projects are now increasingly contributing to many facets of environmental research leading to management and policy outcomes (Edgar et al., 2014, 2016). The increase in activity can at least partially be attributed to the factors already alluded to, but importantly, the data collected by citizens has been shown to in many cases be of equal quality to that obtained by trained marine scientists (van der Velde et al., 2016; Branchini et al., 2015; Chin, 2014; Goffredo et al., 2010; Edgar and Stuart-Smith, 2009).

1.1. Marine virtual citizen science

Many citizen science programs successfully utilise the internet to promote their programs, encourage participation and showcase information collected (Mullen et al., 2013). However, since the rapid expansion of web 2.0 technologies, programs have become more creative in their use of the web and have developed *virtual citizen science* (VCS) projects, (or *citizen cyber science* as they are sometimes called) (Aristeidou et al., 2017; Ren et al., 2012; Nov et al., 2011. Wald et al., 2016; Wiggins and Crowston, 2010; Verhagen et al., 2015). These technologies utilise applications to promote projects and also improve the scientific endeavour, making participation easier and more accessible across wide geographical locations (Jennett et al., 2013, p.2). These technologies are proving to be beneficial to marine VCS projects as they reduce the need for specialised training and because marine science often take place across geographically dispersed locations, the amount of data collected is potentially increased.

Being effective naturally builds interest, and combined with the rapid expansion of web 2.0 mobile technologies, there has been an increase in the number of citizen science programs (Devisch and Veestraeten, 2013), and participation by members of the public, in marine citizen science projects (Graham et al., 2011). Research has found evidence of educational benefits from a VCS, establishing a direct correlation between participation in them and an increase in scientific knowledge of content and processes (Masters et al., 2016). Martin et al.

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https://doi.org/10.1016/j.ocecoaman.2017.10.031
Received 22 June 2017; Received in revised form 31 October 2017; Accepted 31 October 2017
Available online 15 November 2017
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(2016a, p.514) found that people are taking part in marine citizen science because they expect to learn something and thereby make a 'tangible contribution to scientific understanding of the marine environment'. This has resulted in various project achievements, including a whole of system assessment of marine health (Jarvis et al., 2015), generating new understanding of patterns in marine biodiversity (Stuart-Smith et al., 2013), and conservation outcomes through improvements in education and community capacity building (Cigliano et al., 2015).

Research measuring the success of such projects has focused on barriers and motivations for participation (Martin et al., 2016b) and the design principles required for engaging and retaining volunteer participants in an online initiative (Wald et al., 2016). Others have examined the quality of the science and found that applications can sometimes remove the need for extensive training and help produce quality data (van der Velde et al., 2016). However, Franzoni and Sauermann (2014) found citizen science programs have contributed to building scientific knowledge about climate change, but whether that can then be said to represent a tool for social learning or influence behavioural change, requires a case study and formal framework of evaluation to test such assumptions.

2. Method

In this paper using Redmap as a case study (Box 1), we investigated in what ways marine VCS is developing platforms for citizen participation in conservation management. To what extent are such programs making a tangible contribution to environmental management? We explore this question, via analysis of a survey about the VCS program Redmap against Reed's best practice for stakeholder participation in environmental management (Reed, 2008). Reed's principles are as follows:

- *Best Practice Principle 1:* A philosophy that emphasises empowerment, equity, trust and learning.
- *Best Practice Principle 2:* Should involve the public as early as possible
- *Best Practice Principle 3:* Have clear objectives
- *Best Practice Principle 4:* Integration of local and scientific knowledge
- *Best Practice Principle 5:* Ensuring the program is institutionalised.

These principles are useful as they enable deep interrogation of the two key principles of citizen science which are: (i) to develop quality data sets while (ii) involving the public in the research/program. By emphasising learning, knowledge, equity, empowerment and involvement, these principles provide nuance to how stakeholder involvement[1] is achieved, while also providing insights into the institutional dynamics are institutionalised. They thus provide a useful framework to assess citizen science in practice and the extent to which it actually contributes to marine conservation.[2]

2.1. Data collection

In undertaking this investigation, we employed a mixed method qualitative approach, utilising: (i) documentary and content analysis and (ii) a quantitative impact survey of Redmap[3] The project was undertaken between 2013 and 2015 with the survey delivered during 2014.

2.2. Documentary content analysis

Documentary content analysis was used to systematically review both printed and electronic documents about Redmap. Content analysis allows for the organisation and then elicitation of data sources (Bengtsson, 2016): it is a "research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (Krippendorff, 2004, 18).[4]

Documentary content analysis is an efficient, cost-effective, and unobtrusive method that allows researchers to build first-hand knowledge and elicit meaning from which conclusions can be drawn (Bowen, 2009). The data are exact and stable, and cannot be affected or changed by the researcher's presence. Documents also give context and background, raise questions that can be investigated, verify findings from other sources, and are a means of tracking change and development. Tracking change and development is particularly useful in analysing programs and policies. When a particular program has several documents produced by various organisations involved, or where a particular document has several consecutive drafts available, they can be compared to identify changes.

Documents and electronic sites/texts reviewed included journal articles about Redmap, an in depth analysis of the Redmap site itself, newsletters, minutes of workshops, communication and promotion materials, program proposals, program progress reports, and background papers. In total we analysed 28 texts concerning the Redmap project.

2.3. Quantitative survey

We also implemented a national survey of Redmap users to help us understand the extent to which Redmap was meeting its goals and how it was performing as a marine citizen science program. The survey was developed collaboratively between the researchers, the Redmap team, and the Redmap management committee, to refine and adapt it until a final version was produced.[5] The survey was also reviewed and amended by an IT expert to ensure we were asking appropriate questions in relation to the web 2.0 technologies used to collect and record data. We used Survey Monkey (an online survey tool), to ask participants forty questions which focused on the:

(i) utility of Redmap as a tool for citizen science;
(ii) utility of Redmap as a science communication tool;
(iii) useability of the technology;
(iv) reach of Redmap, i.e. how aware are people of it and how useful they find it; and
(v) perceived utility of Redmap to collect verifiable data.

The survey included open-ended questions which asked respondents to reflect on the perceived strengths and weaknesses of Redmap and to do so we used a Likert scale of 1–5 (a commonly used scale to rank people's attitudes).

To obtain participants, the survey was distributed online to 150 registered individuals and groups on the Redmap contact list.

2.4. Triangulation

Triangulation is a technique adopted within the social sciences to

[1] By stakeholders we mean groups of common interest within the marine and fishing sector in Australia who may be affected by climate change. This includes recreational and commercial fishing groups, Indigenous groups, diving, research, tourism and coastal/marine retail stakeholders.

[2] Reed (2008) identified eight best practice principles, but only five were selected for this analysis due to their relevance to the research questions. The remaining three principles were not considered relevant to seeking answers to the research questions as they are focused on analysing establishing and setting objectives for a project plus identifying appropriate stakeholder representation.

[3] This project was approved by the Human Ethics Committee, University of Adelaide in 2014.

[4] Please see the supplementary file for an outline of the process we used for content analysis.

[5] A copy of the survey has been uploaded as a supplementary file.

Box 1
The case study: Redmap

Redmap is a marine VCS program that invites community members to report sightings of marine species that are uncommon to a particular area, i.e., species that may be 'range-shifting' in response to environmental change (Martin et al., 2016a; Pecl et al., 2014, 2017). Redmap was piloted in Tasmania because it is a 'hotspot' for ocean warming, with the waters off the east coast warming at almost four times the global average (Holbrook and Bindoff, 1997; Ridgway, 2007; Johnson et al., 2011; Hobday and Pecl, 2014). However, all of Australia's marine jurisdictions are warming above the global average (Pearce and Feng, 2013; Lough, 2008; Hobday and Pecl, 2014), so in 2012, Redmap was expanded nationally to provide an early indication of what species may be changing distribution is response to warming oceans.

A national Steering Committee oversees the project and is supported by a Science and Data Advisory Committee and a Community Engagement Committee. In each state of Australia, Redmap is led by a local team to create a sense of local ownership over the program however there is a high degree of coordination and collaboration across the country.

There are two overarching aims for Redmap: (i) ecological monitoring to map occurrence of 'new' or 'uncommon' species, usually observed only in warmer waters and (ii) to engage and educate the community on climate change and likely impacts on the marine environment. Sightings and associated information are reported online. Each time a sighting is logged, it is verified for correct species identification by a scientist drawn from an online network of biological and taxonomic experts. The data collected generates an early indication of which species may be shifting geographically, possibly in response to environmental change such as warming waters associated with climate change. The resultant data are used in a range of ways, including structured formal assessments of whether a species is likely to be undertaking a range shift (Robinson et al., 2015), and as indicators of which species may require further scientific examination (eg Ramos et al., 2015; Stuart-Smith et al., 2016).

ensure validation of data from two or more sources (Webb et al., 1966). It allows for the employment and combination of more than one research method to investigate the same phenomenon. This creates added confidence in the results (Denzin, 1970). We utilised three different forms of triangulation:

1. Method triangulation as we collected data from documents, the survey and literature;
2. Investigator triangulation, where more than one investigator collected and analysed the results. In this case, a team of four people worked on developing, sending and analysing results subject to reporting;
3. Data triangulation, where similar messages and patterns are recorded across different data sources.

The use of multiple means of collecting information also helps offset the difficulties of trying to encourage participation in a survey. In our analysis, while there were variations due to data type, we obtained clear consistency around core themes. We conducted the research until we achieved 'information saturation'. This is the point at which it becomes clear there will be no new information and the researcher can assume with confidence that the research has achieved its goals. It is at this point that information collection can cease (Denzin and Lincoln, 2005).

3. Results and discussion

Of the 150 surveys we sent out, we received a 34.7% return rate (52 responses). Many people self identified with more than one category, and of those that responded the following groups could be identified: recreational fishers (37%), beachcombers (8%), boaters (27%), and scuba divers (33%) who comprised the most responses, followed by scientists (15%), with the remainder coming from journalists (4%), communicators (12%), retailers (2%), government personnel (13%), researcher (17%) and teachers (3.85%). No-one identified as either Indigenous or as a commercial fisher". We now present our analysis within the best principles framework and in so doing highlight both the result and add some reflective discussion. The data presented below is a synthesis of our combined analysis of the web site, the surveys and the documents against the principles. However where possible we identify where we draw on specific data sets.

3.1. Best practice principle 1: a philosophy that emphasises empowerment, equity, trust and learning

Key to building longevity in any citizen science program, is establishing a rapport with its participants that will assure ongoing interaction. Trust in the process, equity in access to the program, and capacity to learn from it, are all important elements, and reflected in this principle. Interpretation of the responses provided, demonstrate that Redmap is beginning to build trust and accelerate, or generate, social learning between scientists and the citizens participating in the project.

Active and ongoing participation in Redmap was demonstrated by 98% of respondents specifying they would log an unusual sighting if observed; indicating belief in the utility of Redmap and an awareness that the program is sufficient to promote active engagement and response via logging observations.

Trust is growing between participants and scientists. This is being achieved through active engagement with citizens where logged sightings are verified by the Redmap scientist often in less than one day. Our analysis of the web site itself, and interaction with users at the workshops, shows that the observer is sent a personalised email from the scientist, often with additional information directly relevant to their species or sighting. The promptness of feedback and its nature (direct interaction with expert scientists) has meant users are willing to continue logging sightings and makes them feel like they are part of a learning and a marine VCS community, highlighting the level of empowerment achieved by ongoing quality feedback to users occurs. Open ended survey responses (see Box 2) show that this two-way interaction builds user confidence in the utility of their participation. Generating this feedback is especially important to improve the development of online tools, to ensure users do not feel like they are acting alone, or submitting information into a nameless, faceless site.

When specifically asked, whether or not they trust Redmap (Q 15), 97% of survey respondents said they trusted the information produced via the Redmap project. Box 2 presents some indicative responses as to how the program instilled trust in the respondents. Further, the process whereby submitted data/logins are verified by the scientists, emerged as an important factor, and an aspect of Redmap that was highly valued: "I was impressed that a follow up process was used to verify my sightings" (Redmap Survey Respondent 16, 2013). Data interpretation shows that the verification process was perceived to reflect a high level of transparency, which in turn generated trust in Redmap. Comments also highlight that the 'personal touch' influences positive reception by

Box 2
Indicative survey responses relating to trust in Redmap

"Reputable scientists"
"The photo evidence and verification of observations by scientists"
"The validation of the sightings"
"Verification process by a range of scientists"
"It's an independent source"
"Endorsement of expert scientists in their field"
"The information is logged by keen, enthusiastic community members, and validated by qualified scientists".
"Confidence in the administrators".
"Acknowledgement of local knowledge: divers and especially fishers"
"Direct contact with the very friendly scientists"
"Visual and instant nature of feedback"
"Facilitated by respected research institutions".
"Transparency with the processes that go into classifying species, I can see how it all works"

users of Redmap.

This feedback indicates that despite this being an online tool, the connection to its administrators is an important part of maintaining trust and making users feel important and valued. Roger and Klistorner (2016) echo the importance of this connection when they note that: "there is growing recognition that effective science communication should not merely focus on addressing scientific literacy but must also open dialogue between scientists and the public, build trust, and increase public interest in environmental research".

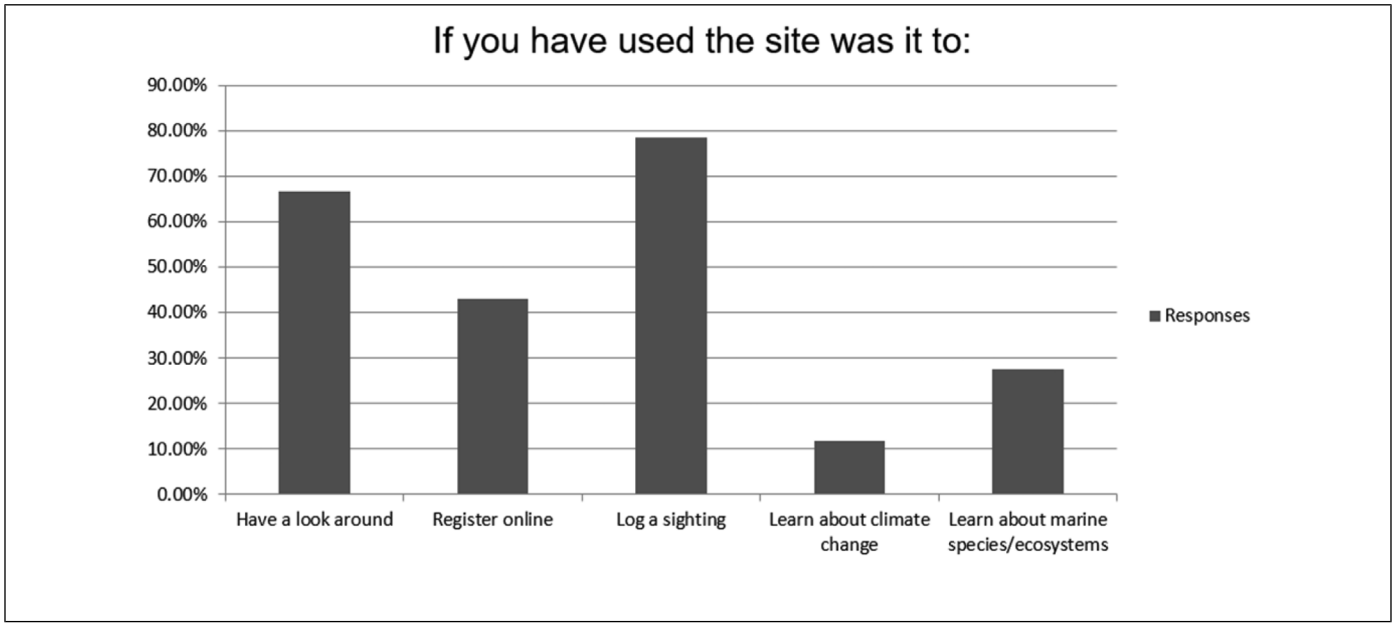
In terms of ongoing learning, Redmap is perceived as a forum by which individuals can access new information. The survey data show that people access the site for many reasons, for instance, people wanted to empower their learning specifically about marine species or climate change (40%) and 49% of all participants noting they learned new scientific information via their engagement with Redmap (see Box 3 below).

The survey results also highlight that participants learned or started to understand that marine species are shifting, and occurring where they normally are not found: "[I've seen]Some more northern species and where they have been sighted in Tasmania" (Redmap Survey Respondent 20, 2013) Over 77% of respondents believed that Redmap was very good to excellent in providing information about which marine species may be shifting and effectively communicating marine climate change (Question 30, Redmap Survey 2013). However, they also sought to have additional information as this quote highlights: "I think it would be cool to have a few brief info sections (with images) categorising the main "habitat types" in which Redmap species are found - e.g. rocky reef, seagrass bed, soft sediment, kelp forest, estuarine etc", (Redmap Survey Respondent 6, 2013).

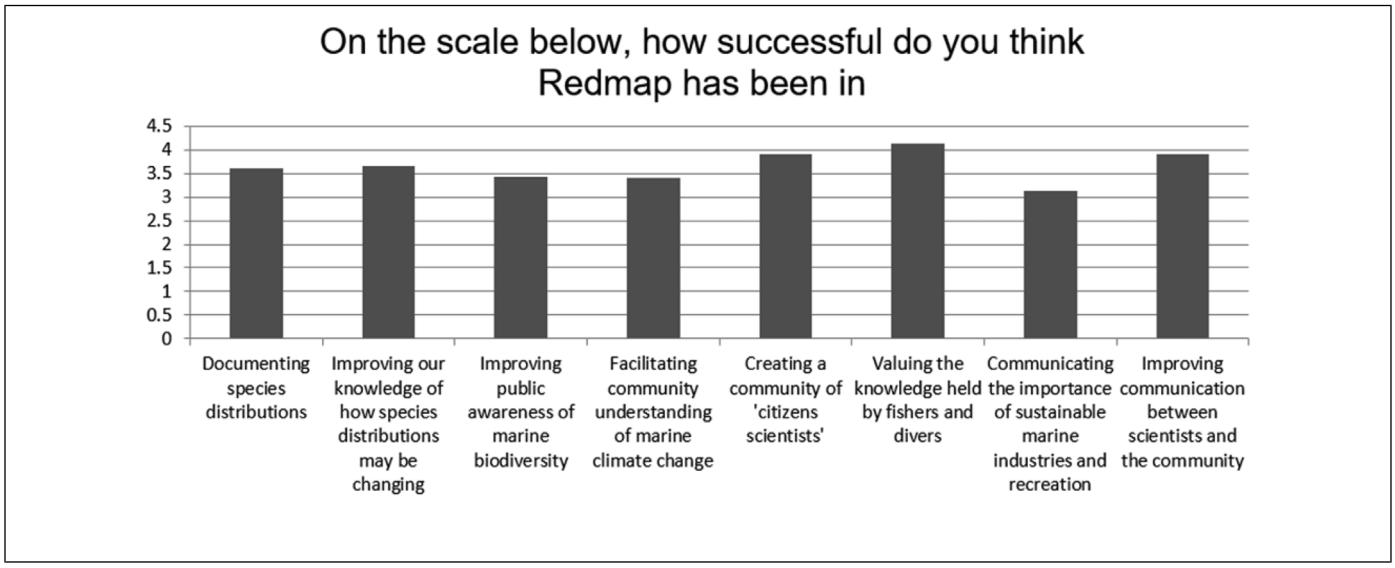
The survey (see Box 4), also highlighted some other learnings. These included feedback that respondents felt they had learned about: (i) documentation of species distributions, (ii) improvement to knowledge about how species distributions may be changing, (iii) improvement to levels of public awareness of marine biodiversity, (iv) facilitation of community understanding of marine climate change, (v) creation of a community of 'citizens scientists', (vi) a valuing of the knowledge held by fishers and divers, (vii) communication of the importance of sustainable marine industries and recreation and (viii) improved communication between scientists and the community. The survey results show a relatively even distribution amongst how respondents perceived the different types of learning that had occurred.

The data also show that many people use Redmap to not only log

Box 3
When asked about why they used or accessed the Redmap web site respondents noted the following (Question 11, Redmap Survey 2013): -



Box 4
Other learnings identified by Survey Respondents (Question 13)


On the scale below, how successful do you think Redmap has been in
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Documenting species distributions
Improving our knowledge of how species distributions may be changing
Improving public awareness of marine biodiversity
Facilitating community understanding of marine climate change
Creating a community of 'citizens scientists'
Valuing the knowledge held by fishers and divers
Communicating the importance of sustainable marine industries and recreation
Improving communication between scientists and the community

information but also receive it (see Box 3 for examples of 'out of range' sightings). Of those who participated in the survey, 49% had visited the website to access new articles about marine science and 78% did so to learn about new species. Hence, Redmap is creating a two-way learning process suggesting Redmap may act to spur behaviour, and is therefore not just something people know about. The following quote highlights that users also disseminate their learnings in the broader community: "It captures my interest in cataloguing marine species. It is a way for me to contribute my understanding of marine biodiversity to the broader community" (Redmap Participant 11, 2013). Some users evidenced clear satisfaction with their experience, noting that their participation had in turn encouraged and motivated them to learn more about species (see Fig. 1).

Further, almost half of the survey respondents felt they had learnt new information. For example, our investigation shows that Redmap users achieved five key learning outcomes resulting from their interaction with the program including:

1. Knowledge about new range extension sightings;
2. Knowledge about fish species and distributions;
3. Information about what was happening in other parts of Australia;
4. Insights into the relevance of having accurate species information incorporated into policy decisions
5. What other species changes and distributions are occurring.

Interestingly, we found that 'new information' ranged from obtaining knowledge about the very local (species being found in home grounds) to obtaining higher level knowledge about what is happening in other parts of Australia: Box 5 provides some examples.

3.2. Best practice principle 2: should involve the public as early as possible

Reed (2008) argues that early adoption by the public should occur from the outset when developing a participatory scientific process. In this case, Redmap is a VCS focused on public participation in the gathering of data that may contribute or provide context to future decisions regarding the management of marine resources that are being impacted by a changing climate. We interpret involvement to mean both participation in the project per se, as well as involvement in its formation.

Our analysis of the various newsletters, minutes of workshops, media reports and other documents shows that Redmap has consistently invited community input at various stages of construction and development: this was reflected in survey responses to open ended questions: "Great way of encouraging citizen science, clever integration with social networking, easy to use interface, really proactive promotion and communication of the project to a range of community groups, great outreach" (Redmap Respondent 7 2013). Various community stakeholders (within Australia only) were invited to participate in initial and subsequent workshops discussing project components and implementation. A Community Engagement Committee was established as part of the institutional support structures available to the Redmap community. Furthermore, community members have been invited to engage on project expansion (such as the development to a national-scale project and addition of a phone application as a data collection tool). These occasions also included consultation over which species to list in each state, what information they were comfortable to report or not, feedback on the website design and function, the logo and look of the project and then they were consulted on the text and design of the report card which reports the major data outputs from the project. The Redmap program has also invested in a wide range of promotional collateral, such as floating key rings (for use on boats), posters, reusable water bottles and branded USBs, all of which have been distributed via fishing, scientific, research and media networks across Australia. These have been physical ways in which the program tried to build and encourage community involvement in the program, and by which community members were incorporated into promoting its activities. Analysis of the web site, and documentary analysis also highlighted the delivery of a video competition in 2014. In this competition, Redmap invited the public to send in a 45 s video about Redmap that raised awareness of ocean warming. The first prize was AU $2000 and all entries were loaded onto the Redmap web site and used for promotional purposes. This competition attracted 35 entries and provided a different entry point to involve the public in disseminating science. Over 70,000 people viewed these videos. Redmap also has a Facebook site which creates another entry point for community engagement in their activities. The Facebook page typically engages between 5000–20,000 people each week, sometimes more if a particular activity like the video competition is occurring.

Interestingly despite the high visibility created by the activities described above, over 50% of the survey respondents said they knew people that were familiar with Redmap but do not use it while an additional 45% noted they had only heard of Redmap by 'word of mouth' Some of this may be explained by survey respondents not yet making an

Fig. 1. Participants in the Redmap Australia project pictured with the 'out-of-range' observations they logged online. Top: Tom Srodzinski with his first Yellowtail kingfish (*Seriola lalandi*) caught from the Tasman Peninsula, off Tasmania (photo credit: Jonah Yick), and bottom: a red emperor *(Lutjanus sebae*) caught off Green Head, Western Australia (photo credit: James Florisson).

observation that fits the Redmap criteria (i.e. a species spotted outside its expected geographical distribution). Others suggested that a mobile app would help create wider dissemination and access to Redmap: "Create more apps that will work on standard devices recreational fisherman take out on their boats (eg mobile phones)", (Redmap Respondent 16). Redmap has now produced an app in response to this query. However, this result suggests that while Redmap is creating awareness about its work, it is not necessarily receiving broader uptake by citizens, in terms of logging sightings. Specifically, our study shows that it is the recreational community (fishers and divers) that are most engaged with the program and from whom approximately 90% of sightings are derived. This finding demonstrates that other major marine users, especially the commercial fishing sector, are not taking part in the marine VCS program. Critically, there is much latent capacity for Redmap to work on building public involvement in the program by key stakeholders.

3.3. Best practice principle 3: have clear objectives

This principle derives from the rationale that clear research questions are more likely to result in robust answers (Lynam et al., 2007) determining whether a program is meeting its objectives. As noted earlier, Redmap established two objectives: (i) ecological monitoring as an early indication of what species might be shifting where they live as a response to warming waters; (ii) to engage and educate the community on issues around marine climate change. Review of the web site itself, shows a clearly structured digital information platform, that uses its information to virtually engage users but also provides a wide range of information about the species that users are logging about. Further analysis of the survey against this principle suggests that users understand Redmap's objectives and provides an insight into what it is achieving as a VCS tool. Generally, survey results highlight positive respondent feedback that asserted that Redmap has been 'very good' at achieving its objectives and in particular, felt that it had been effective at creating 'a community of citizen scientists', 'valuing fishers' knowledge' and 'improving communication between scientists and the community'. There were no negative comments or issues in relation to user and public understanding of Redmap's goals.

Implicit in the responses and relevant to this criterion is the fact that respondents indicated a high satisfaction with the useability, accessibility, and ease with which submissions could be made with 47% of all survey respondents indicating it was 'easy to use' (Question 24, Redmap Survey, 2013). This speaks to the fact that the program, as an *online* citizen science tool, has succeeded in being clear not only about its

Box 5
Examples of new information obtained by users from Redmap

- New range extension sightings
- I am constantly learning what the natural distribution of particular species are. Also, the extent to which climate change is impacting our marine species.
- A large variety of marine species are showing range extensions in Western Australia
- Fish species and distribution
- How to identify turtles
- What was happening in other parts of Australia
- Specifics of projects being undertaken relevant to my policy work
- That there are different species of fish found in areas, and that they will move from their usual habitat if there are changes in water temperature.
- Which species are changing their distribution patterns.
- The identity of a sea creature we found
- About how far some species come down (the coast)
- Some more northern species names and where they have been sighted in Tasmania
- New species names
- Range extensions - ie dolphin fish at Tasman peninsula

objectives, but has also enabled citizens to use the site to obtain and submit the information needed to meet those objectives. However, results show that further work is required to enhance Redmap's capacity to 'facilitate community understanding of marine climate change' and in 'communicating the importance of sustainable marine industries and recreation'.

3.4. Best practice principle 4: integration of local and scientific knowledge

The integration of knowledge systems is an implicit goal of citizen science programs, although it is acknowledged to be a challenging part of the process (Pulsifer et al., 2014). In this case, integration is defined as the bringing together of community sightings and scientific knowledge about the species. Overall, our information reveals that users think that integration *is* occurring via the verification process. The verification process is the part of the Redmap project that aims to bring the VCS participants and trained scientists together. The verification process is seen to successfully integrate both local and broader scientific knowledge sets in a way that is building a sense of community.

For example, 85.7% of respondents said they were aware that a scientific panel of experts, which they believe is transparent and open, verifies all photographs submitted to Redmap. This finding is important because participants indicated that transparency is important to them as it means there is less likelihood of sightings being 'manipulated' and may act as a disincentive to those who may try and 'cheat' the system. One respondent commented that 'some [photos] are better than others, in regards to fishing photos, more emphasis should be placed on photographs of live fish, rather than dead ones'. This highlights the challenges of developing a program that unifies two clearly different groups – fishers and divers – with often different value systems when it comes to marine systems.

However, critical feedback about what other content or knowledge type participants could contribute, showed that a number of respondents (20%) had additional ideas about enhancing the content for Redmap. These included requests for provision of information about what species are of interest to different areas, ocean water temperature data, up-to-date Sea Surface Temperature (SST) data, logging data about when species are sighted and more information on marine invertebrates.

Generally, individuals thought that additional information would help build their own confidence when describing various fish and habitats, thus increasing the descriptive accuracy of their sighting and the integration of knowledge. It is also worth noting that while integration of knowledge sets occurs between the recreational and scientific community, the commercial and Indigenous sectors are under-represented in Redmap sightings. This is because, (despite sending the survey to both Indigenous and commercial fishing groups) we did not receive any submissions from them. We do not know why these groups did not participate, but the lack of information from them means we cannot assess this dimension in relation to their participation or experience, and is an area requiring future and targeted follow up. The knowledge integration, therefore, could be wider and more diverse in the future and this latent capacity could be built on as Redmap expands.

3.5. Best practice principle 5: ensuring the program is institutionalised

Key to analysing our data against this criterion was the question of how to define the term 'institutionalised'. In this case, we take it to mean ways in which the program has gone beyond being an 'output from a grant', to a program that has developed enough momentum to encourage institutions to invest in it and the extent to which it has in and of itself *become* an institution. In this case, Redmap has wide institutional reach. Firstly, its host institution, the University of Tasmania, supports it. By inviting academic, industry, and government personnel to serve on and chair the Steering, Community and Scientific Committees, the Redmap team also ensured institutional support from across the nation and across many other stakeholder/interest groups and institutions.

In becoming a national program, Redmap has become an entity that is helping drive discourse and action on and about citizen science in a marine VCS context. Furthermore, it facilitates collaboration with over 80 researchers from across the country, involving over twenty research institutes, links to multiple environmental organisations, museums, and various government agencies across the country. This collaboration has been aided by the fact that Redmap has a clear and consistent brand, an easily recognisable logo and catch phrase and defined communication and engagement strategies.

4. Implications: the utility of virtual citizen science

Overall, our investigation found that users perceive Redmap to be enhancing scientific knowledge about climate change impacts on the marine environment, and has created a limited platform that facilitates active citizen participation. We also found that only certain key stakeholders tended to participate so there is potential for future exploration of the less represented groups such as Indigenous peoples and commercial fishers. Further, due to the relatively young history of Redmap, we still could not empirically determine a link between the evidence of social learning we documented and actual behavioural change (i.e to fishing practice); this is another area that would benefit from future exploration.

From the perspective of its citizens/users, Redmap is perceived to be meeting its objective to map the occurrence of 'new' or 'uncommon' species. However, while it is evident that whilst users *are* learning about *new species*, this survey could not ascertain the extent to which they link this with *climate change*. Nonetheless, we argue that overall, the results highlight that citizen science can play a potential role in environmental management regimes. For example, in terms of contributing to stakeholder engagement in environmental management, Redmap is starting to establish a useful data base, as well as heightening awareness about the need to manage in response to changes in the environment.

Moreover, given the connectivity of the marine domain, utilising online tools creates a novel capacity for data entry as it can be used anywhere and anytime. This type of information, as it builds will be a important source of information which can be used as a springboard for environmental decision making at various scales. Fishers and divers from across Australia can record observations from anywhere by accessing Redmap via their mobile device. As Clark (2014) reflects, the uptake of web-based reporting and use of smartphone technology transforms social influence through its revolutionary information creation, curation, and distribution. In this case it has transformative potential in terms of assisting in environmental management.

VCS programs also have the capacity to create space for combined learning about key environmental challenges, such as climate change (Wals et al., 2014). We argue, that our results show that by creating a forum for joint expression of multiple voices (both scientific and non-scientific), Redmap has begun to chart a method by which multiple voices, integrated with cultural perspectives and scientific theory, authenticate, inform and encourage more participatory and community-based orientation (Wals et al., 2014). By engaging communities in this way, Redmap has created a new and national community of practice (Wenger, 1998) where people are working together for a common purpose.

Redmap as a VCS also enables a community engaged scholarship by setting individual observations in the context of a whole data set about the possible impacts of climate and other stressors on marine environments. This is a form of social learning and has the potential to emancipate, and build scientific literacy within the community. Redmap as a VCS facilitates a convergence between science and environmental education that catalyses practical and meaningful research (Wals et al., 2014). Importantly, the building of community literacy about key issues may have the longer-term benefit of building trust in

science and scientists in a context where controversy frequently exists. In doing so, this approach offsets difficulties in enjoining citizens to participate in issues related to climate change. As Lassen et al. (2011) point out, citizen 'calls to action' in relation to climate change are often indirect and obtuse, so in being specific in what it is seeking, and as presented in its slogan "Spot. Log. Map", Redmap offers a specific opportunity to participate in and create learnings around the impacts of climate change in marine contexts. Indeed, Carvalho et al. (2017) argue that effective 'communication practices not only help create the conditions for political engagement but they also comprise the modes of such engagement', and are crucial for effective citizen engagement with climate change.

VCS in this respect can act as a platform and process for social learning by enabling citizens to incorporate knowledge about and thus cope better with the complexity of inter-dependent human and ecological processes. Reed et al. (2010) describe social learning as "a process whereby individuals, groups, and/or organizations choose to take an active role in decision making processes that affect them" and harnesses the importance of observation in building community learning (Bandura, 1971). Citizen science as a process of social learning can support individuals to go beyond themselves and mobilise collectively to be drivers for change; it can promote institutional flexibility and malleability and help transform knowledge as facts into knowledge in practice. As such, it fosters ways of thinking in volunteers that may be consistent with how scientists view the world which is crucial for future decision making (Trumbull et al., 2000; Jordan et al., 2012). Further, VCS programs like Redmap act to enhance the potential for social learning tools by creating a space for citizen input that transcends geographical boundaries. In this context, we emphasise the importance of building virtual tools for understanding fluid domains such as the marine environment and which enable social learning about it.

Finally, we suggest that VCS such as Redmap have the capacity to become a virtual boundary organisation, one that links science and community. Boundary organisations create communities of practice to build multi-party and collaborative governance processes (Pahl-Wostl et al., 2007). By acting as bridging organisations, virtual programs link actors across multiple scales to address and solve problems that would be inconceivable on an individual basis (Crona and Parker, 2012). This linking also enables adaptive capacity for different forms of governance, facilitated through the mutual learning that occurs online. A VCS is therefore a form of performative practice within a participatory governance approach, enabling citizenship to be "constituted in interaction in the context of participation" (Turnhout et al., 2010: 1).

5. Conclusions

Citizen science has a role to play in facilitating the conditions for community engagement with environmental issues, facilitating social learning by trust building, developing engagement pathways and breaking down conventional barriers between citizen and scientist. Citizen science can also help generate shared understandings between scientists and participants, and generate methodologies that bring together stakeholders and scientists to co-produce knowledge and decisions (Stocker et al., 2012) and build towards better and stronger planning and management (Macaraig, 2015).

While the Redmap program still has some challenges, and certainly could build the diversity of the stakeholders that use it, as a marine VCS it has overcome many of the historical challenges of conducting marine citizen science programs. Its use of web 2.0 technologies provide insights to other VCS initiatives and demonstrates that VCS programs have the potential capacity to build citizen awareness and learning about key management issues such as climate change. In so doing, they also have started a conversation about how to use citizen based information to help inform and shape future decisions about ocean and coastal management.

Author information

All authors have experience in the marine and fisheries space but with different foci: Associate Professor Nursey-Bray focusses on social learning and community engagement and Associate Professor Pecl is a marine ecologist who examines species responses to climate change. Rob Palmer is a science communications specialist, PhD candidate in the discipline of media at the University of Adelaide and has extensive experience working with fishing communities.

Conflicts of interest

None.

Acknowledgements

This study was supported by the Australian Government Inspiring Australia initiative. GP was supported by an ARC Future Fellowship. We would like to thank the many citizen scientists and other participants in the Redmap Australia program, and in particular the respondents to our survey. We would also like to acknowledge the support and help of the Redmap Australia team, including Yvette Barry, Jemina Stuart-Smith and Elsa Gartner.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2017.10.031.

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